Opportunities for Exploring Longitudinal Dynamics in Heavy Ion Collisions at RHIC

RIKEN BNL Research Center Workshop
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Some thoughts on the longitudinal correlations

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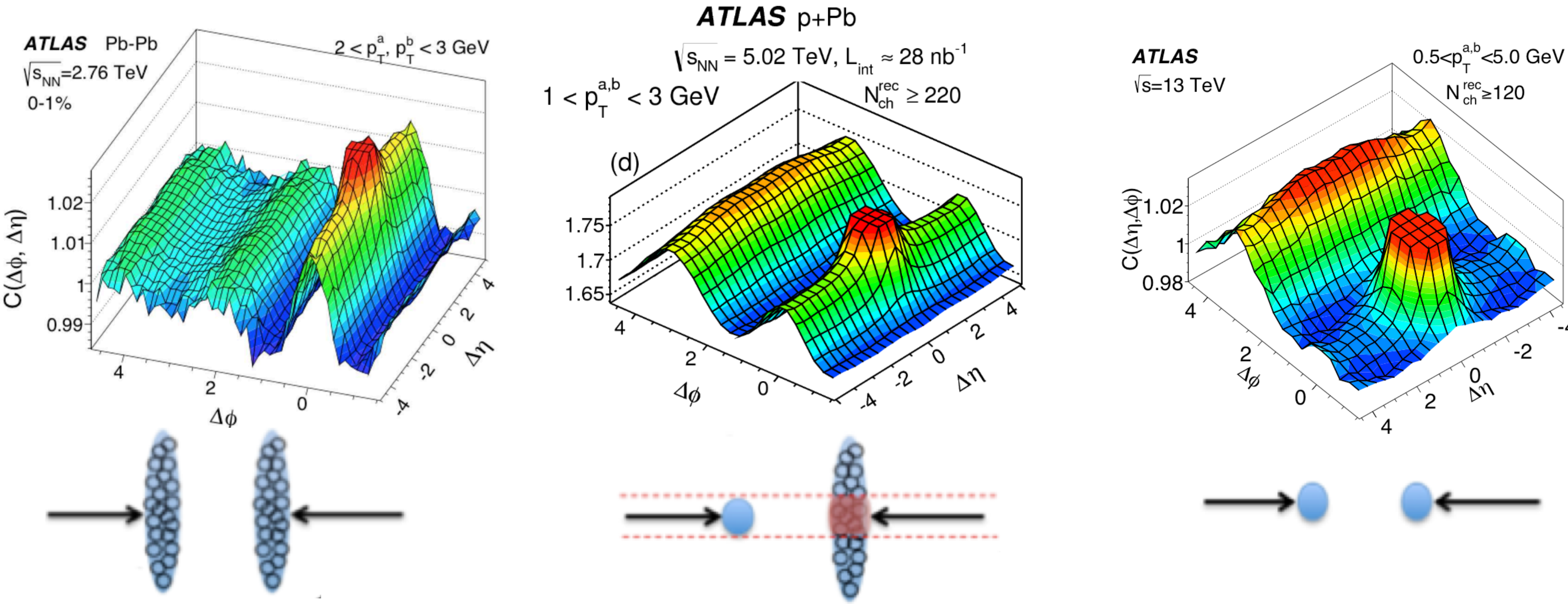
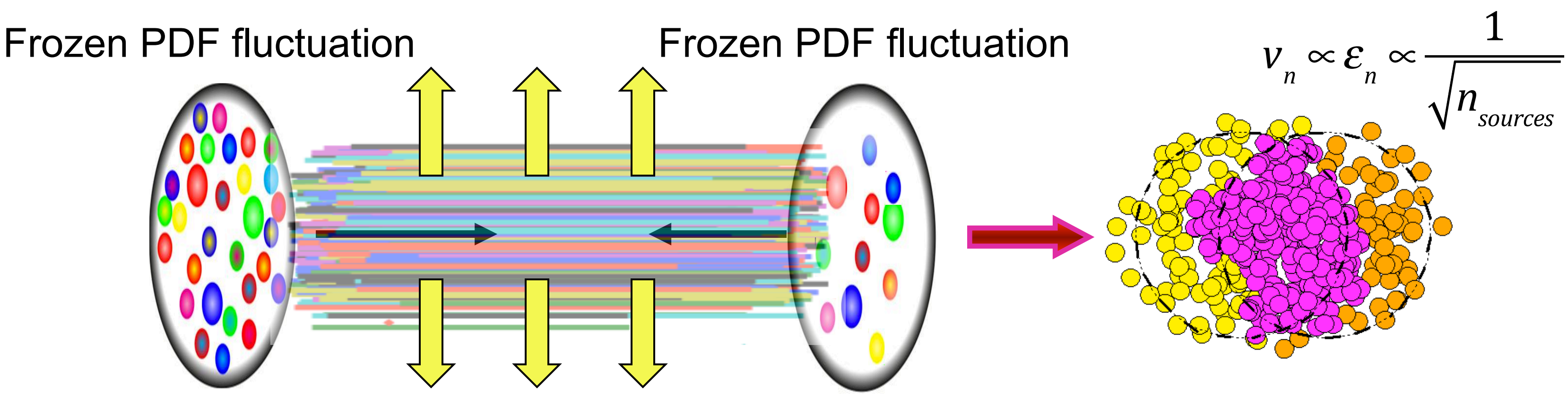
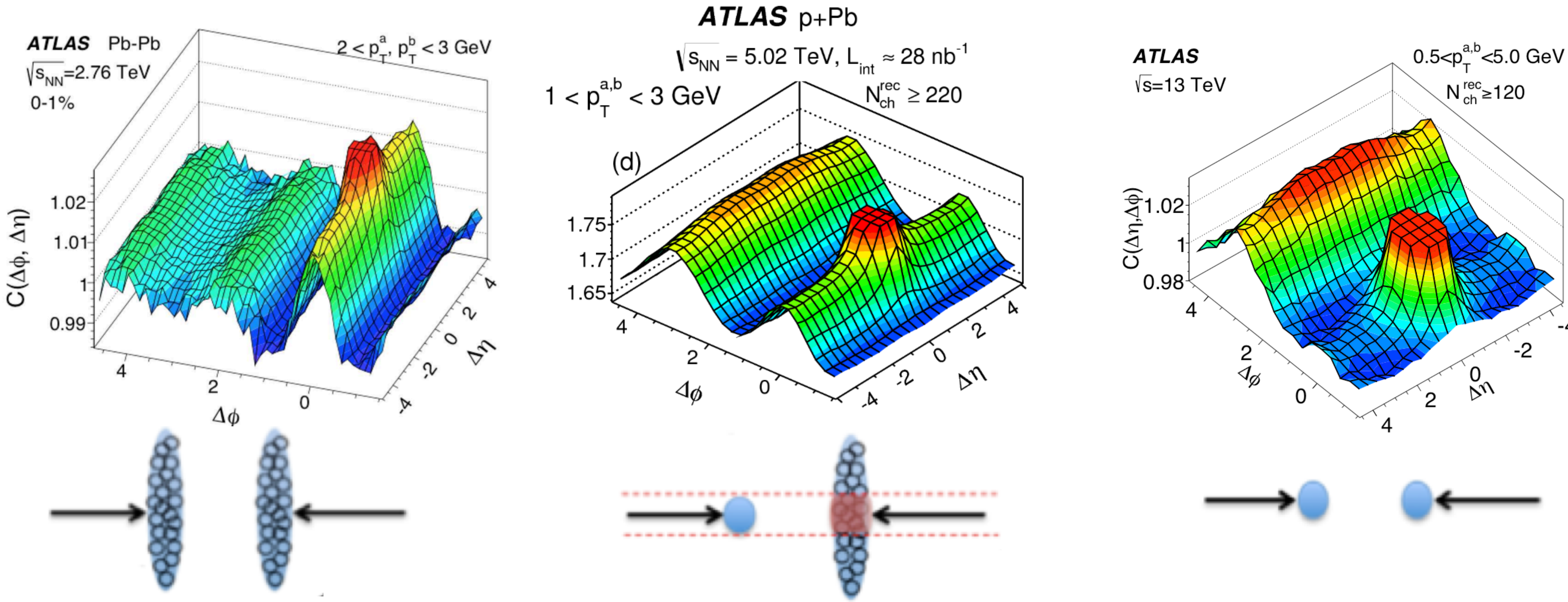


What sources seed these long-range collective ridges?



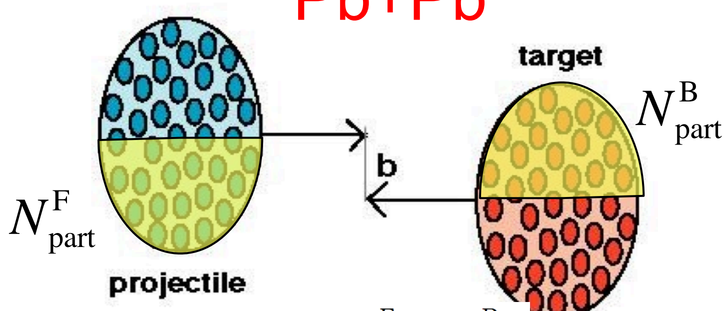
How many such sources, their sizes & transverse distribution?



What sources seed these long-range collective ridges?

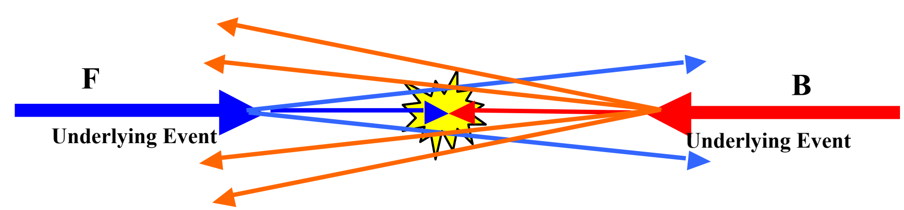
Particles (entropy) are produced early in collision

Pb+Pb



$$A_{part} = \frac{N_{part}^{F} - N_{part}^{B}}{N_{part}^{F} + N_{part}^{B}}$$

p+p



MPI: $n_f \neq n_b$

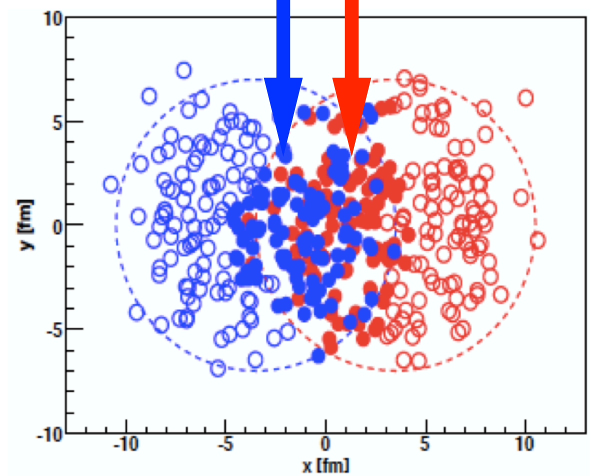
$$A_n = \frac{n_f - n_b}{n_f + n_b}$$

forward/backward multiplicity/flow correlations provide a handle

Three types of longitudinal dynamics

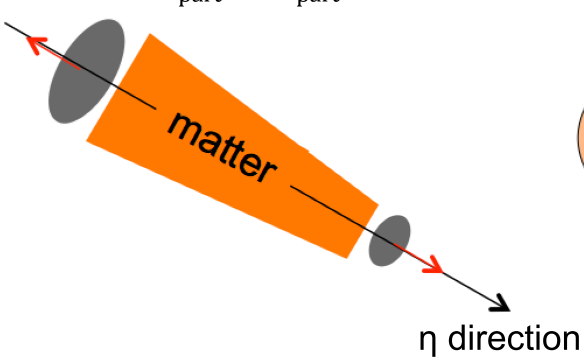
Fluctuation participants in two nuclei → difference in size and event-shape

$N^{\mathrm{F}}_{\mathrm{part}}$ $\varepsilon^{\mathrm{F}}_{n} e^{in\Psi^{F}_{n}}$ $N^{\mathrm{B}}_{\mathrm{part}}$ $\varepsilon^{\mathrm{B}}_{n} e^{in\Psi^{B}_{n}}$



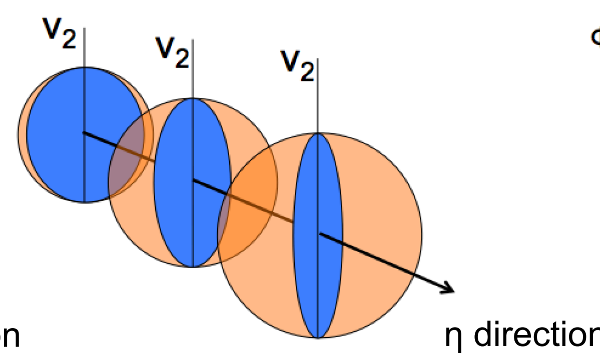
Consequences:

(a) $N^{\mathrm{F}}_{\mathrm{part}} \neq N^{\mathrm{B}}_{\mathrm{part}}$



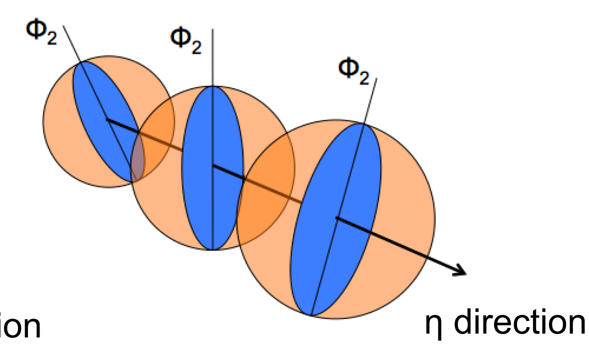
Asymmetry in multiplicity

(b) $\varepsilon^{\mathrm{F}}_{2} \neq \varepsilon^{\mathrm{B}}_{2}$



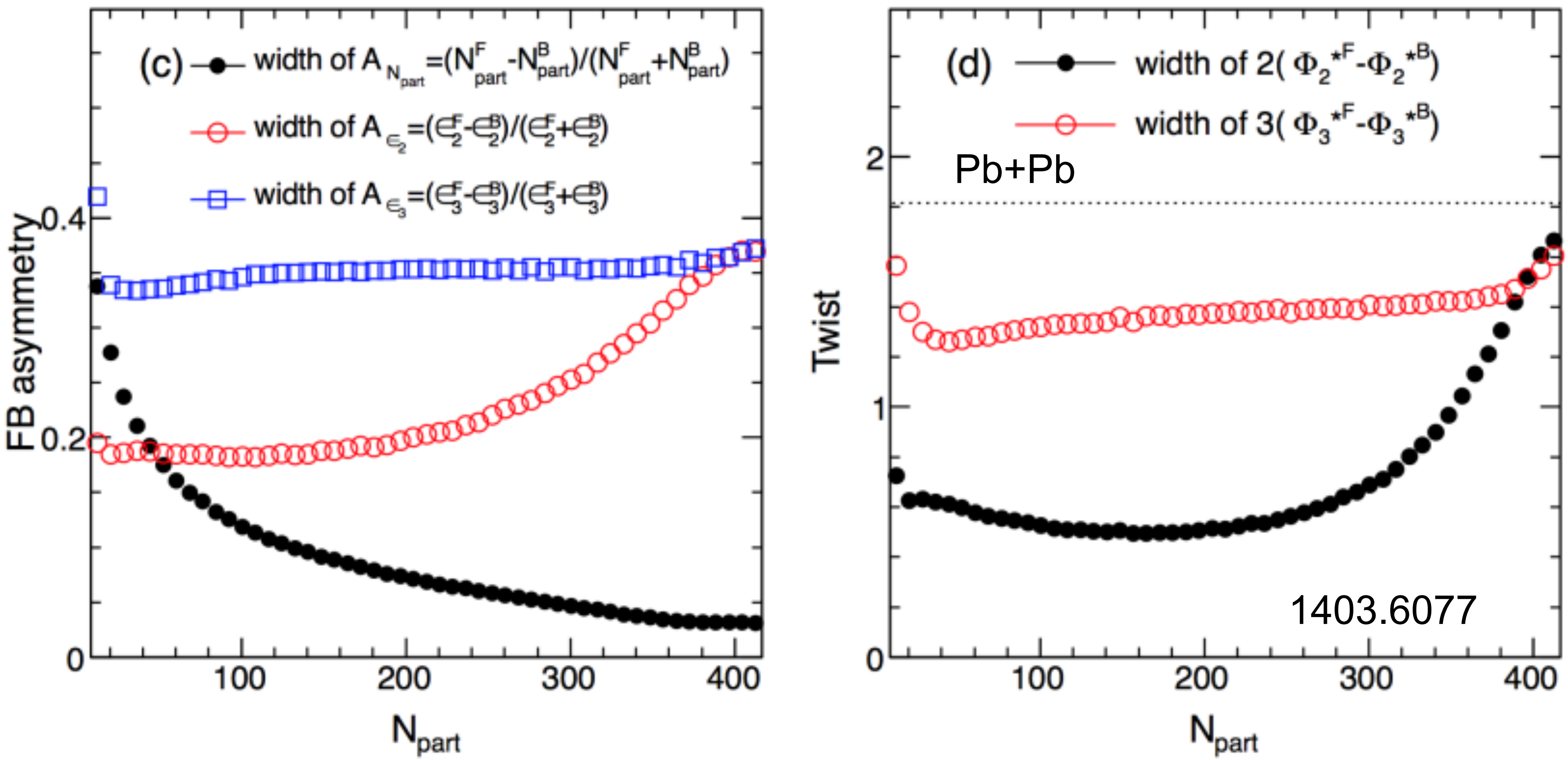
Asymmetry in flow magnitude

(c) $\Psi^{\mathrm{F}}_{2} \neq \Psi^{\mathrm{B}}_{2}$



Torque/twist of flow plane

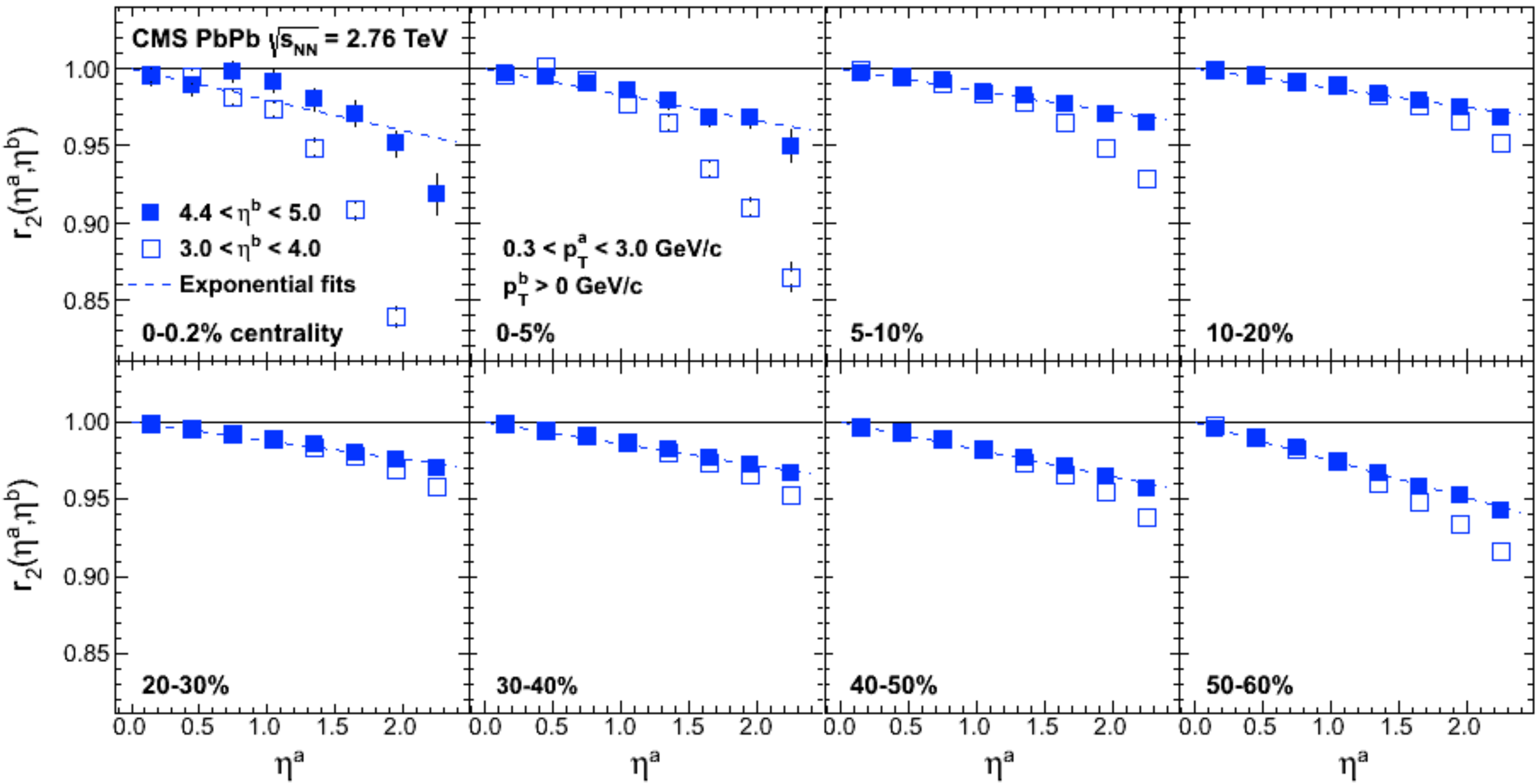
Glauber model estimation



- N_{part}-asymmetry large in peripheral.
- 2^{nd} order: ε-asymmetry and twist largest in central
- 3^{rd} order: ε-asymmetry and twist ~ independent of centrality

2^{nd}-order flow

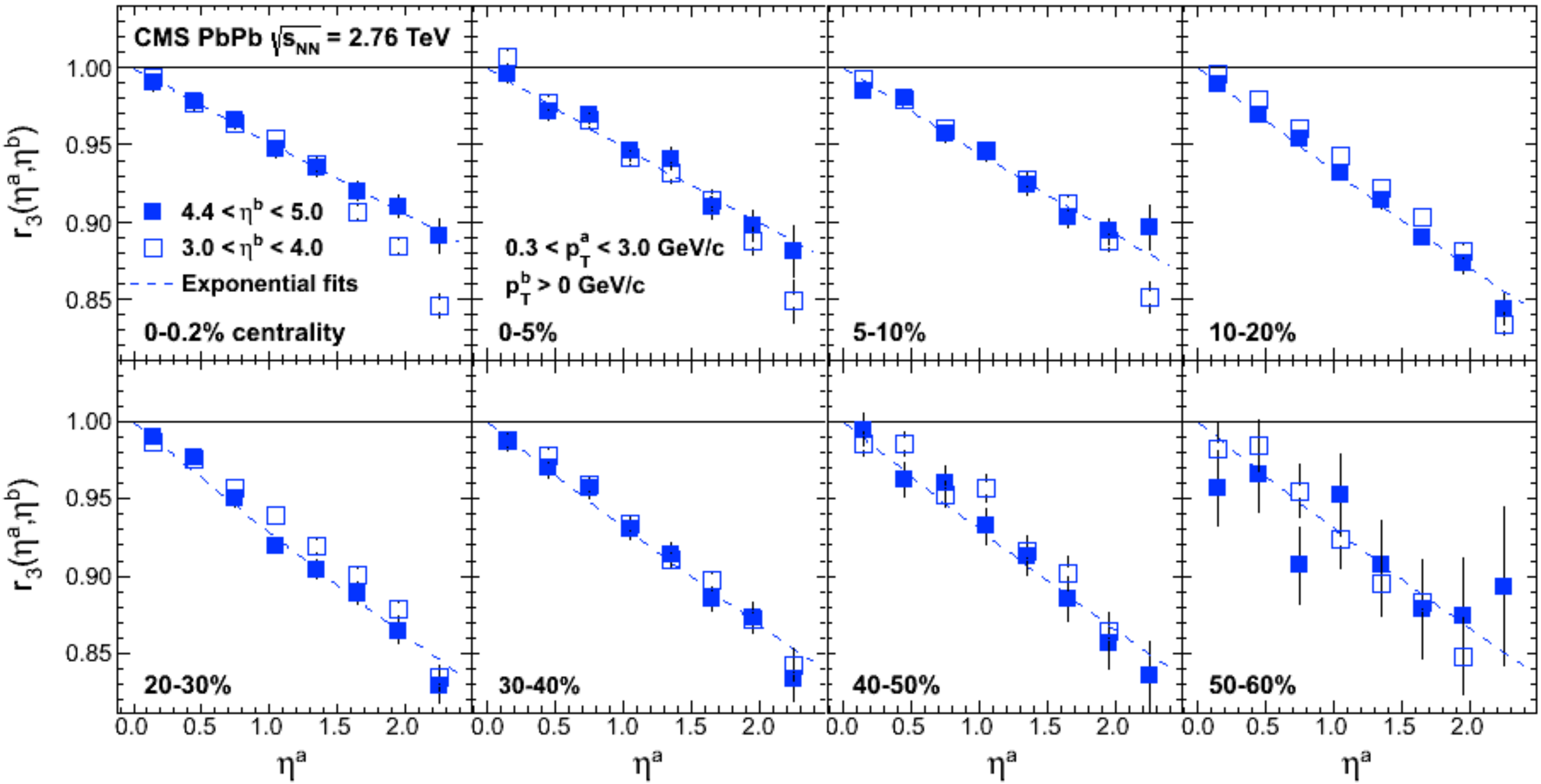
$$r_n(\eta^a,\eta^b) \equiv \frac{V_{n\Delta}(-\eta^a,\eta^b)}{V_{n\Delta}(\eta^a,\eta^b)}$$



- Decrease toward mid-central collisions, then increase toward peripheral collisions

3^{rd}-order flow

$$r_n(\eta^a,\eta^b) \equiv \frac{V_{n\Delta}(-\eta^a,\eta^b)}{V_{n\Delta}(\eta^a,\eta^b)}$$

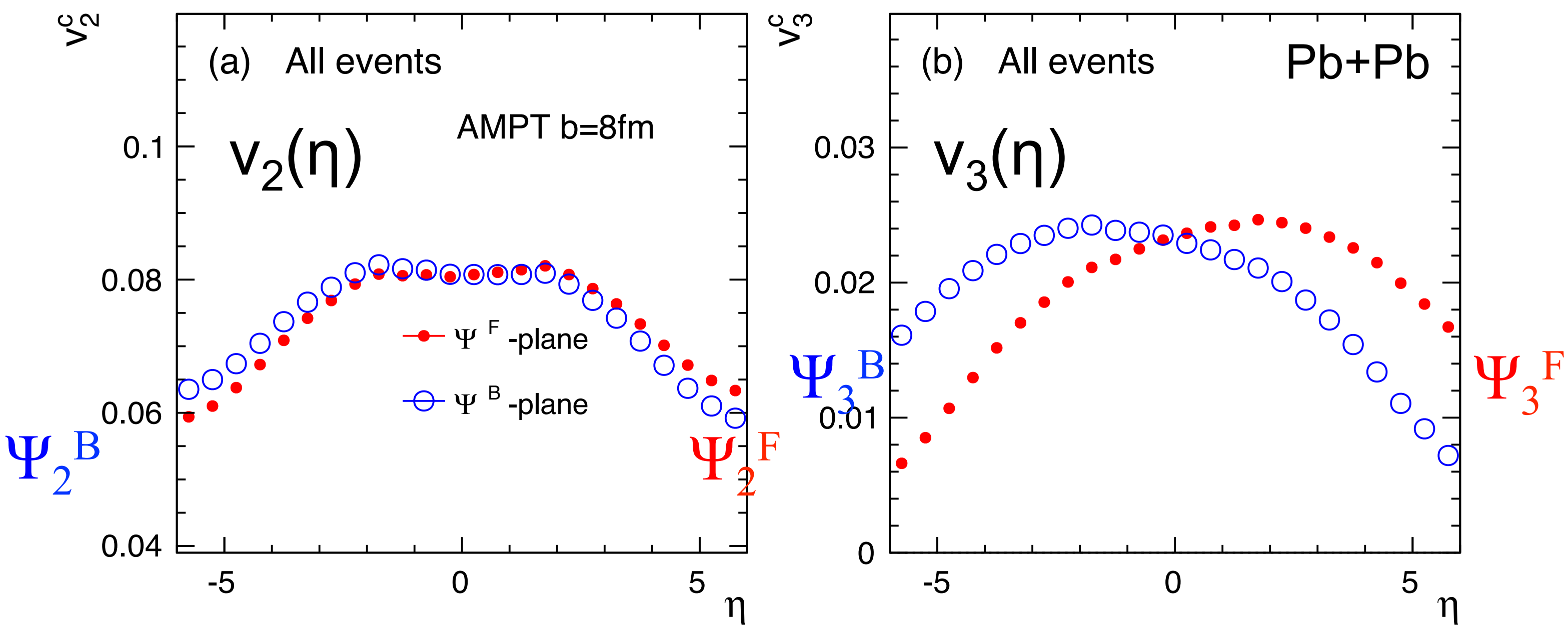


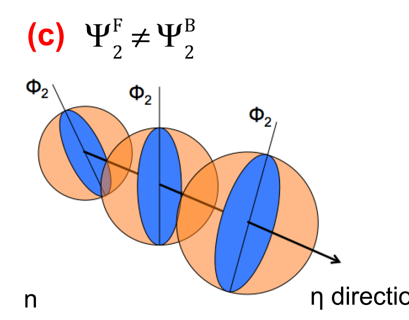
- Slight increase toward peripheral collisions
  - → Other component of flow, e.g. subleading flow, subnucleon dof

Decorrelation effect in AMPT

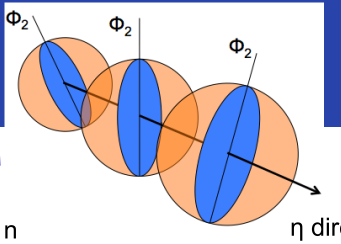
- Both ε-asymmetry and Ψ-twist effects are large in AMPT
- Measure v_n using $\Psi_n{}^F$ or $\Psi_n{}^B$ separately.

→ Results depend on which participant plane used, strong influence of decorrelation



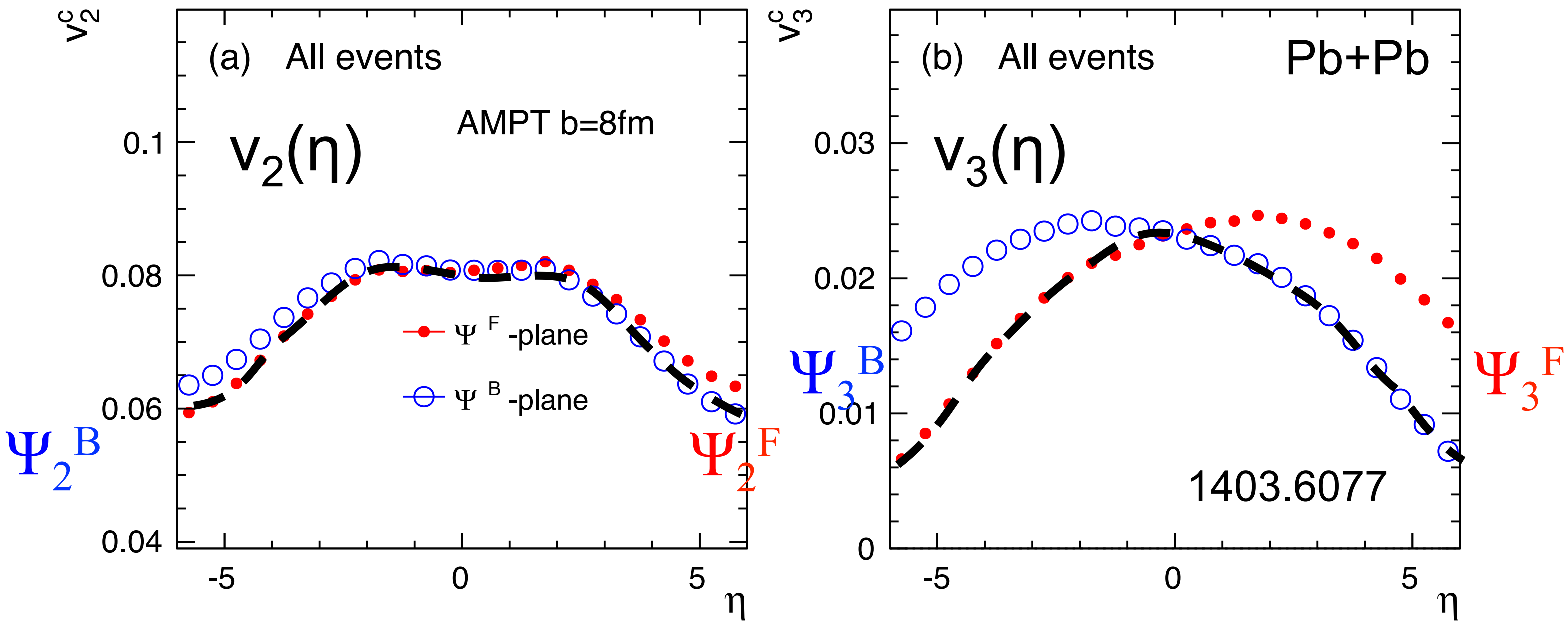


Decorrelation effect in AMPT



- Both ε-asymmetry and Ψ-twist effects are large in AMPT
- Measure v_n using Ψ_n^F or Ψ_n^B separately.

→ Results depend on which participant plane used, strong influence of decorrelation

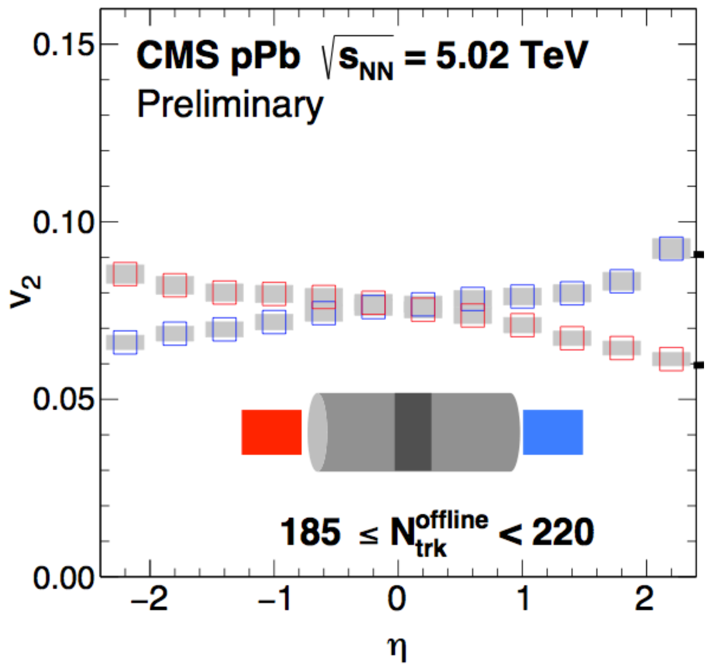


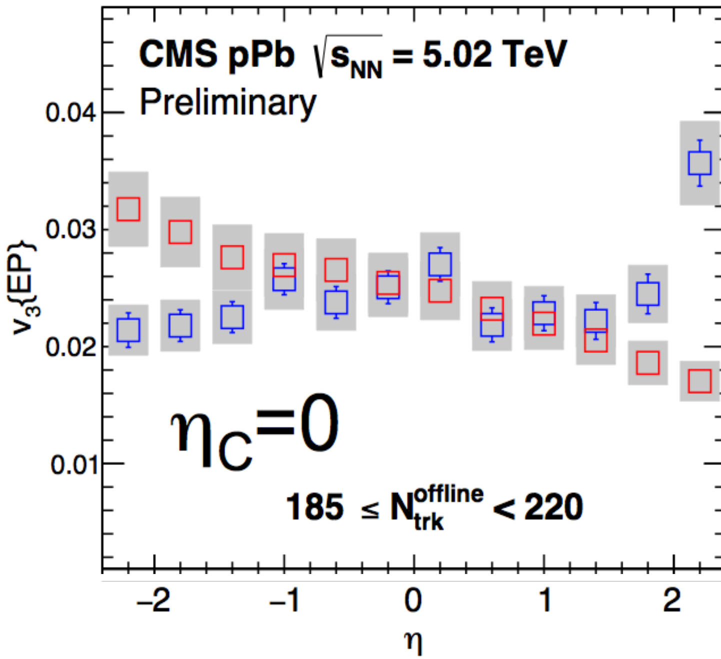
- Most analyses require η gap, and present symmetrized results

→ Leads to characteristic triangular shape for $v_3(\eta)$ around η=0

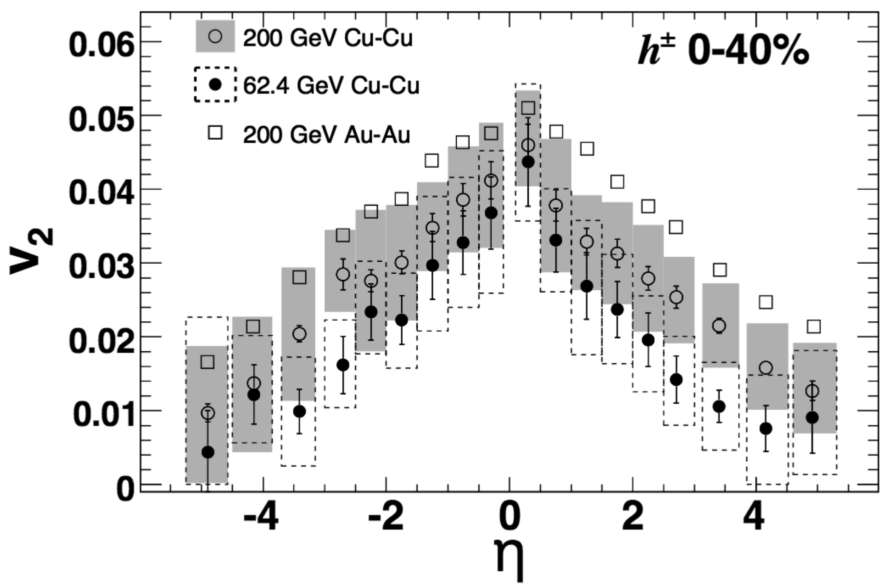
Indeed seen in the EP analysis

Hint of this seen at LHC

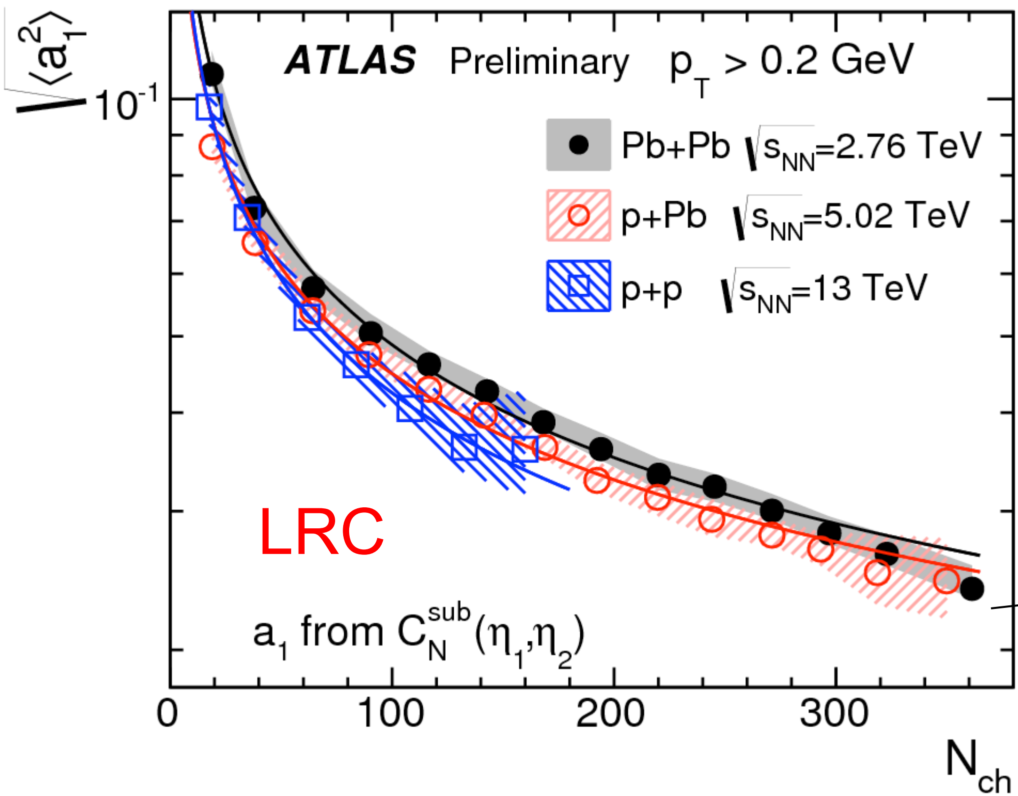


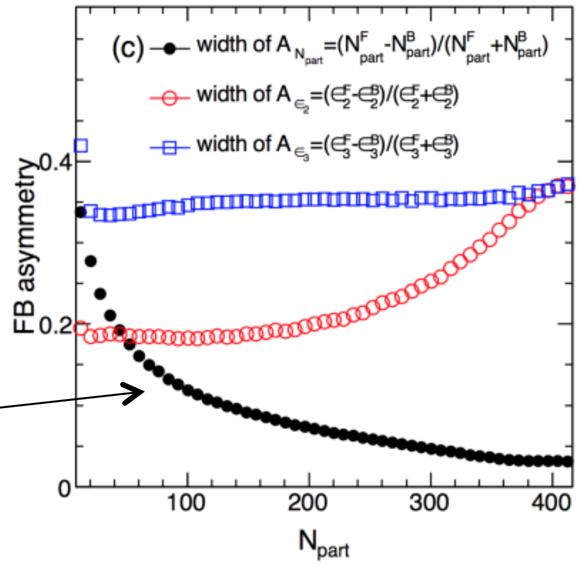


stronger effect at RHIC



0^{th}-order: FB multiplicity asymmetry





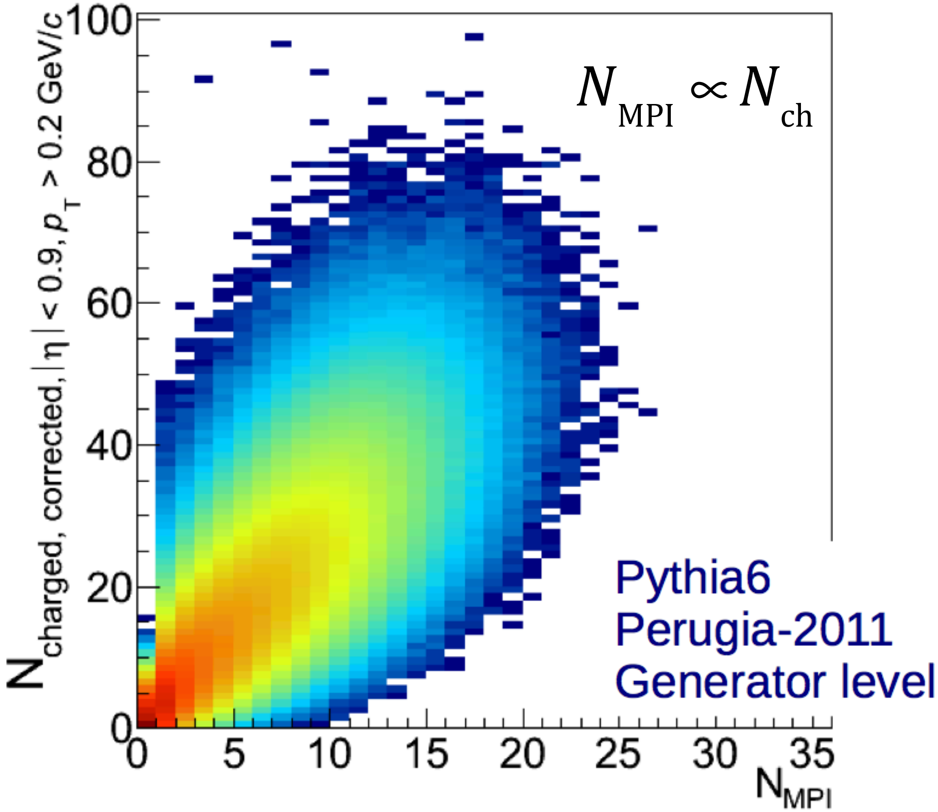
- $1/\sqrt{N}$ behavior is seen independent of collision system

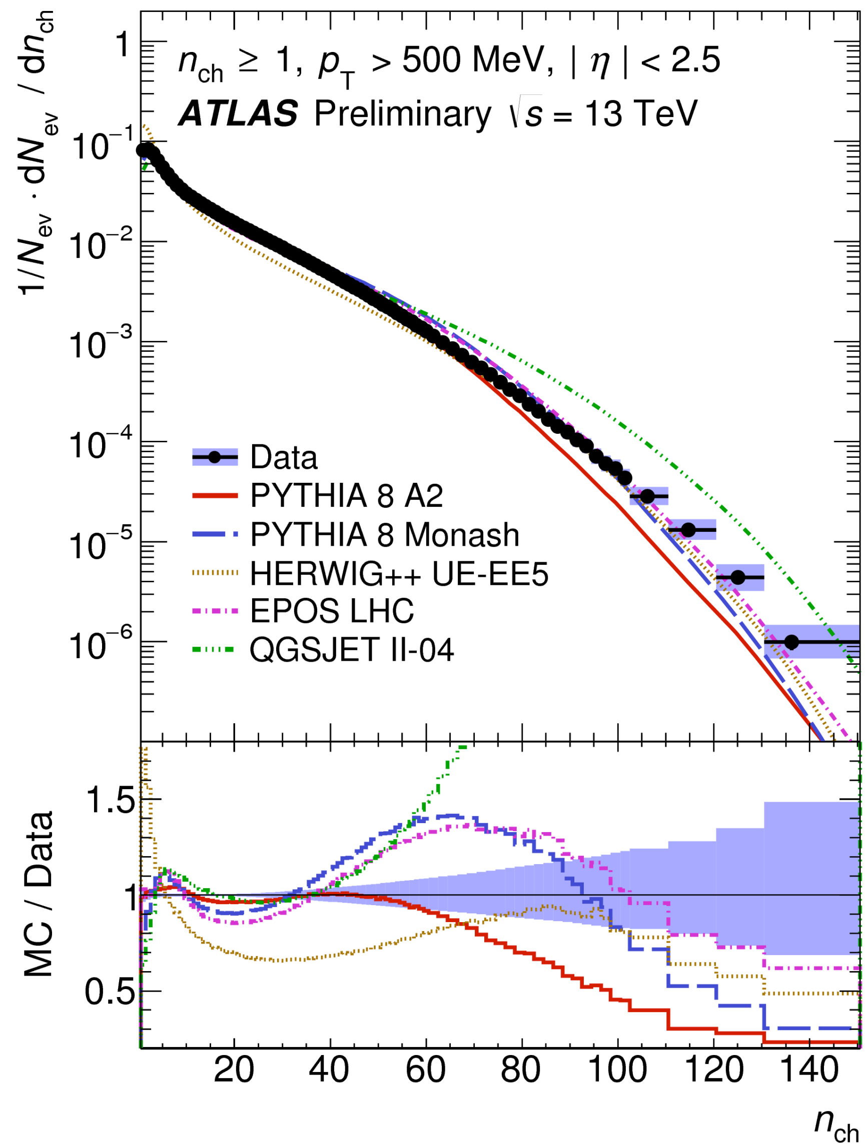
→ Think in terms of partons (via e.g. MPI)

Importance of sub-nucleonic sources

- Multi-parton interactions (MPI) required to described N_{ch} distribution

$$\langle N_{\mathrm{MPI}}(p_{\mathrm{T,\,min}})\rangle = \frac{\sigma_{\mathrm{interaction}}(p_{\mathrm{T,\,min}})}{\sigma_{\mathrm{non\text{-}diffractive}}}$$

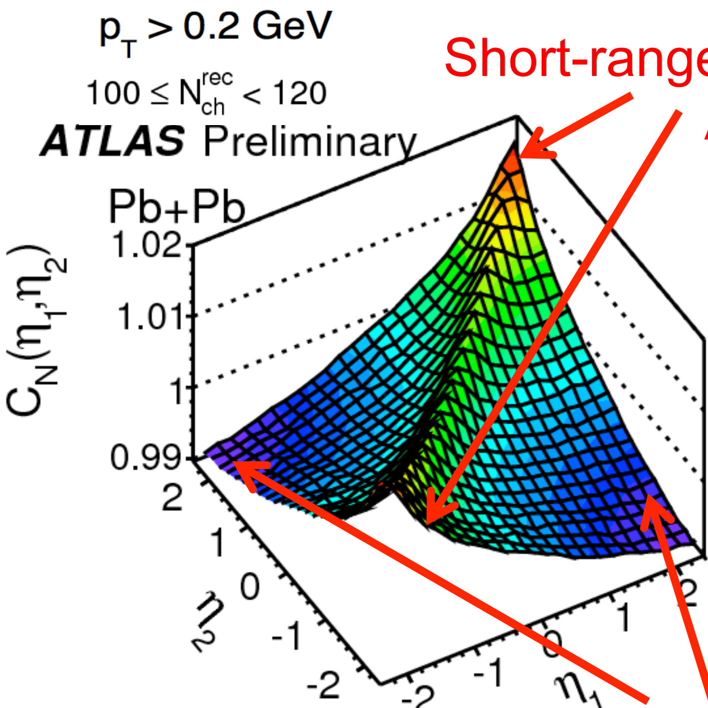




- N_{MPI} proportional to N_{ch}

A bit more detail on FB multiplicity correlation

Property of the multiplicity correlation



Short-range correlation $\delta_{\mathrm{SRC}}(\eta_1, \eta_2)$

$\Delta\eta=\eta_1-\eta_2\sim 0$

Long range correlation $\mathrm{LRC}(\eta_1, \eta_2)$

large $|\Delta\eta|$

Data-driven method to separate SRC from LRC

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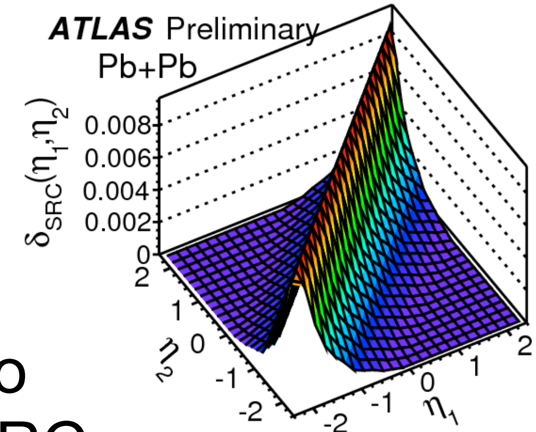

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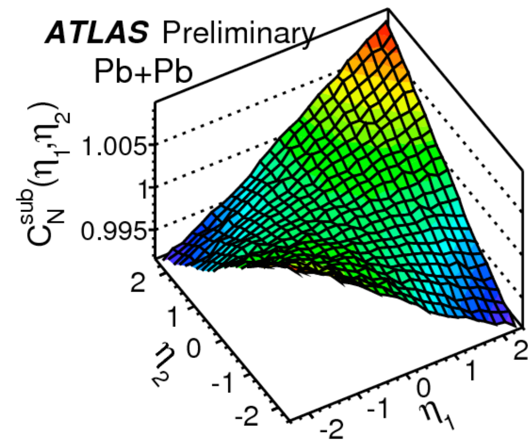
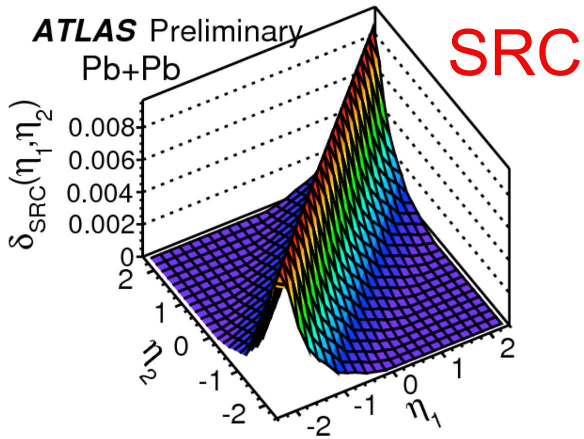


- SRC reflects correlations in the same source
- LRC reflects FB-asymmetry of number of sources, e.g. $A_{\mathrm{part}} = \dfrac{N_{\mathrm{part}}^{\mathrm{F}} - N_{\mathrm{part}}^{\mathrm{B}}}{N_{\mathrm{part}}^{\mathrm{F}} + N_{\mathrm{part}}^{\mathrm{B}}}$

Quantifying the SRC and LRC



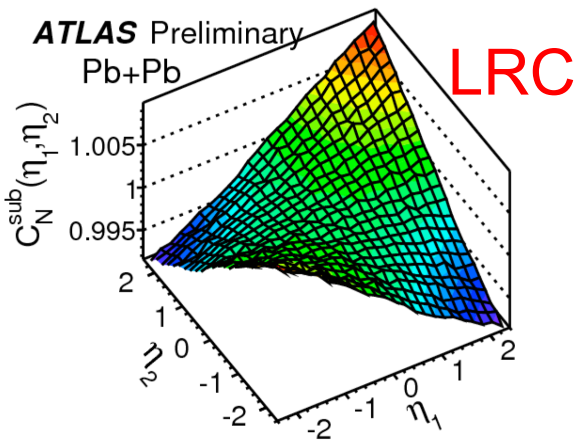
Quantify by average amplitude:

$$\Delta_{\mathrm{SRC}} = \frac{\int \delta_{\mathrm{SRC}}(\eta_1,\eta_2)\,d\eta_1 d\eta_2}{4Y^2}$$

$|\eta|<Y=2.4$

$p_T > 0.2$ GeV

$100 \le N_{ch}^{rec} < 120$



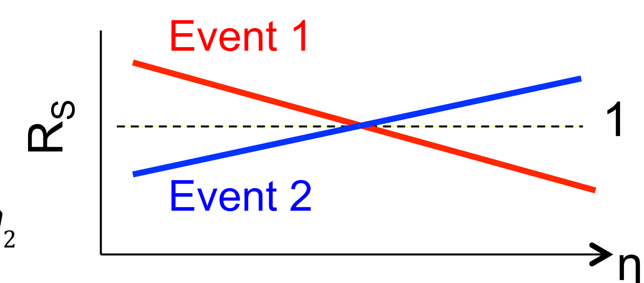
Shape approximate by:

$$C_{\mathrm{N}}^{\mathrm{sub}}(\eta_1,\eta_2) \approx 1 + \left\langle a_1^2 \right\rangle \eta_1\eta_2$$

Implication: deviation from average is linear in η

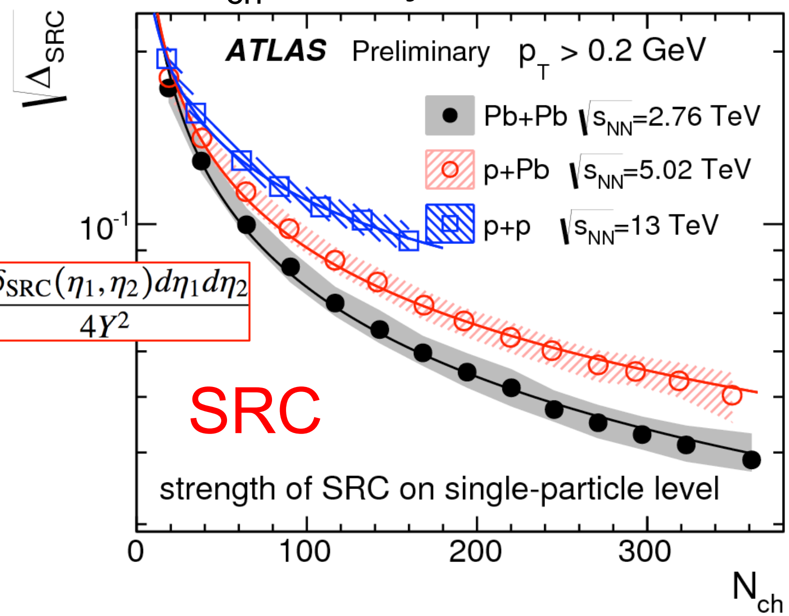
$$R_S(\eta) \equiv \frac{N(\eta)}{\left\langle N(\eta)\right\rangle_{evts}} \approx 1 + a_1\eta$$

$$C = \left\langle R_S(\eta_1) R_S(\eta_2) \right\rangle \approx 1 + \left\langle a_1^2 \right\rangle \eta_1\eta_2$$



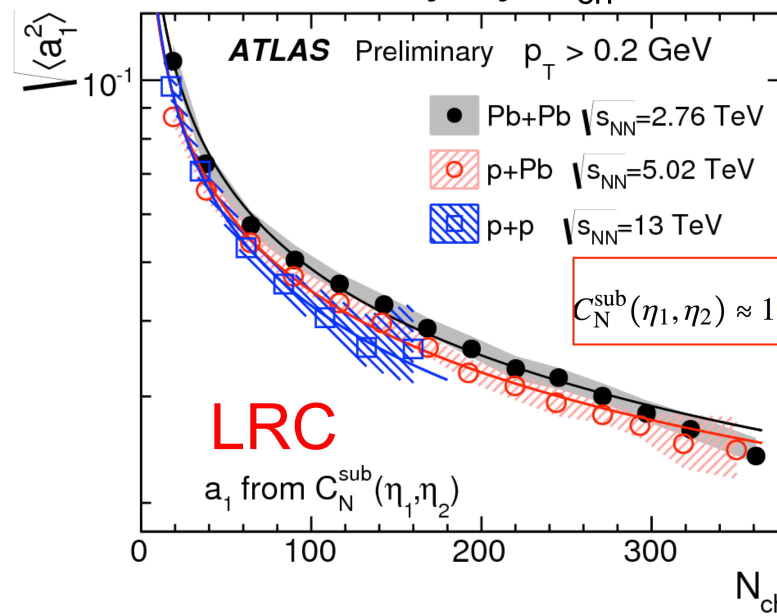
Dependence on N_{ch} and collision systems

both N_{ch} and system size



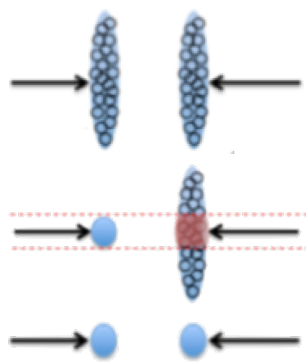
$$\Delta_{SRC} = \frac{\int \delta_{SRC}(\eta_1,\eta_2)d\eta_1 d\eta_2}{4Y^2}$$

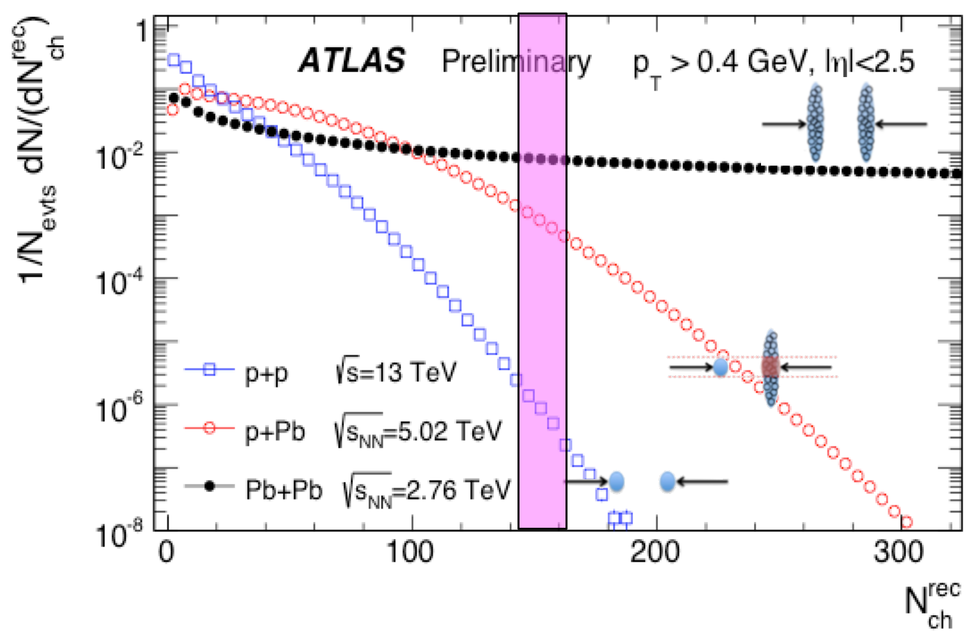
only by N_{ch}



$$C_N^{sub}(\eta_1,\eta_2) \approx 1 + \langle a_1^2 \rangle \eta_1 \eta_2$$

Compare:



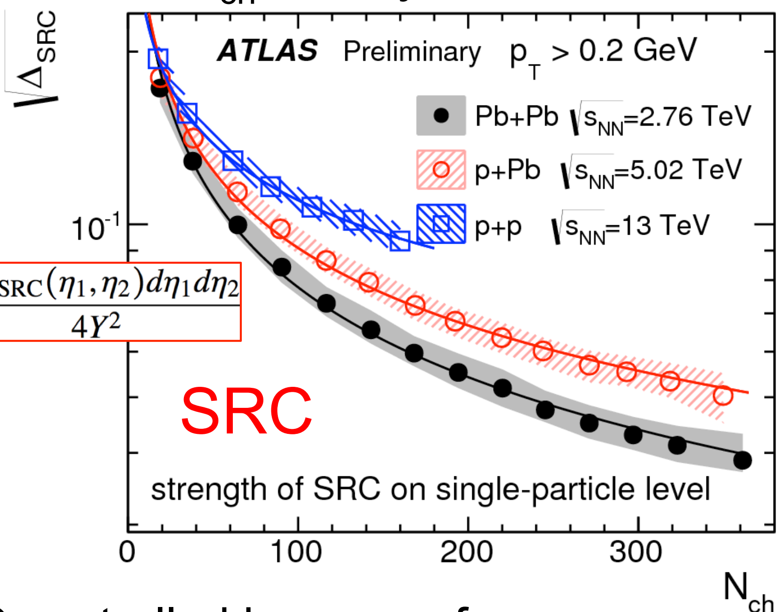


SRC/LRC control by

N_{ch} or transverse geom. size?

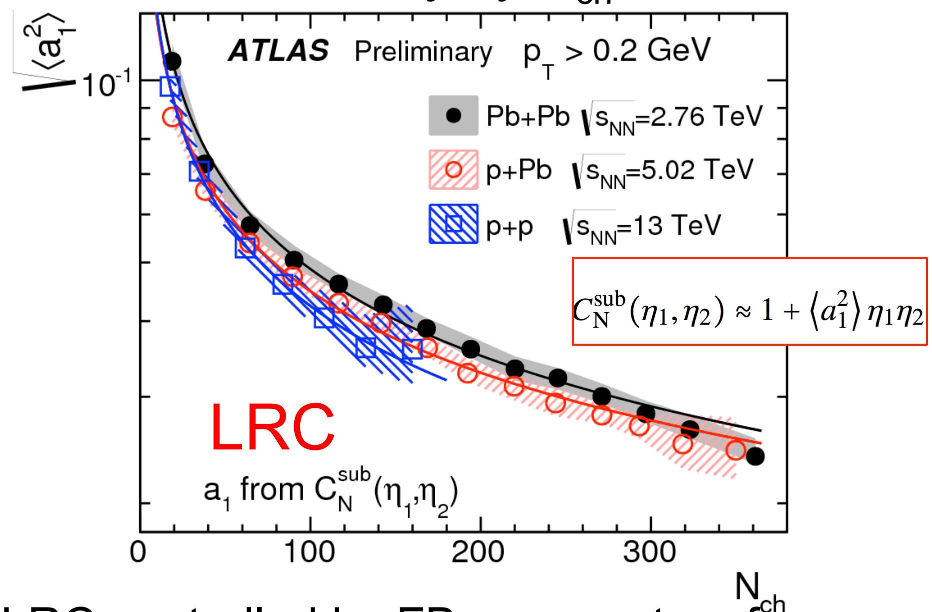
Dependence on N_{ch} and collision systems

both N_{ch} and system size



$$\Delta_{\rm SRC} = \frac{\int \delta_{\rm SRC}(\eta_1,\eta_2)d\eta_1 d\eta_2}{4Y^2}$$

only by N_{ch}



SRC controlled by num. of sources

$$\boxed{n = n_f + n_b \propto N_{\rm ch}}$$

LRC controlled by FB asymmetry of sources

$$\boxed{A_n = \frac{n_f - n_b}{n_f + n_b}} \qquad \langle a_1^2\rangle \propto \langle A_n^2\rangle$$

"independent source picture": $\sqrt{\Delta_{\rm SRC}} \sim \sqrt{\langle a_1^2\rangle} \sim \frac{1}{n^\alpha} \sim \frac{1}{N_{\rm ch}^\alpha}, \alpha \sim 0.5$

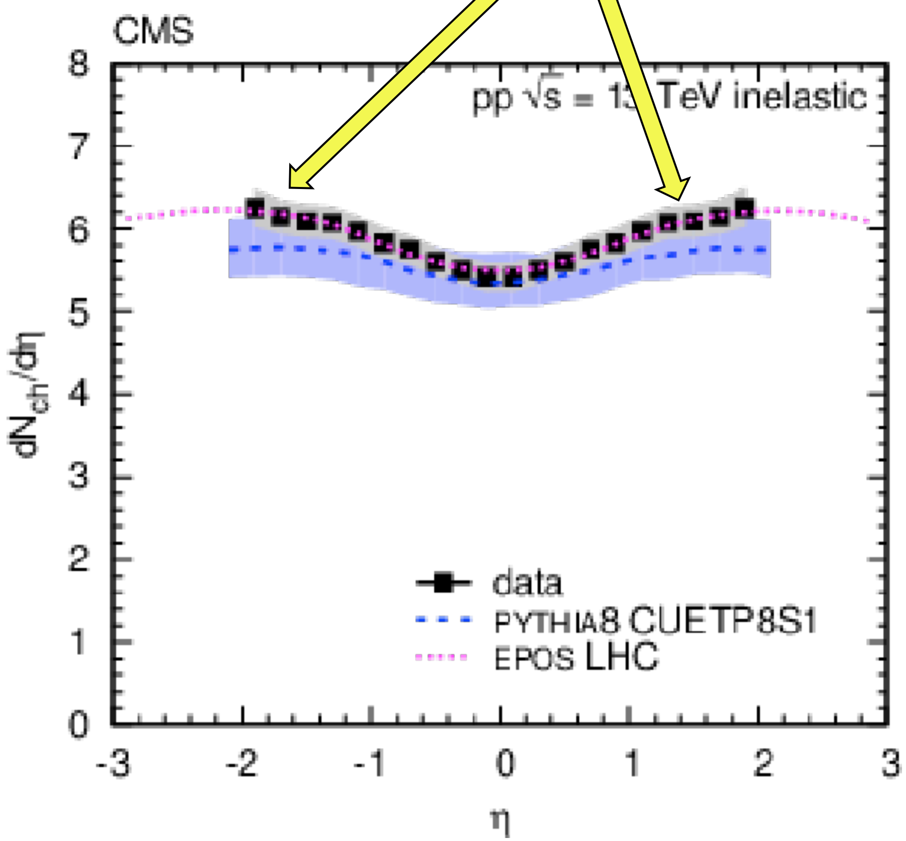
- Fit with $c/N_{\rm ch}^\alpha$

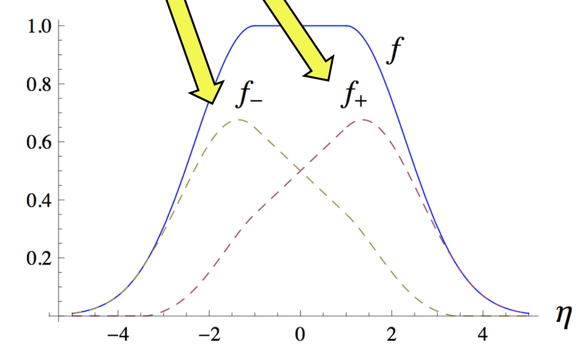
	Pb+Pb	p+Pb	pp
α for $\sqrt{\Delta_{\rm SRC}}$	0.502 ± 0.022	0.451 ± 0.020	0.342 ± 0.030
α for $\sqrt{\langle a_1^2\rangle}$	0.467 ± 0.011	0.448 ± 0.019	0.489 ± 0.032

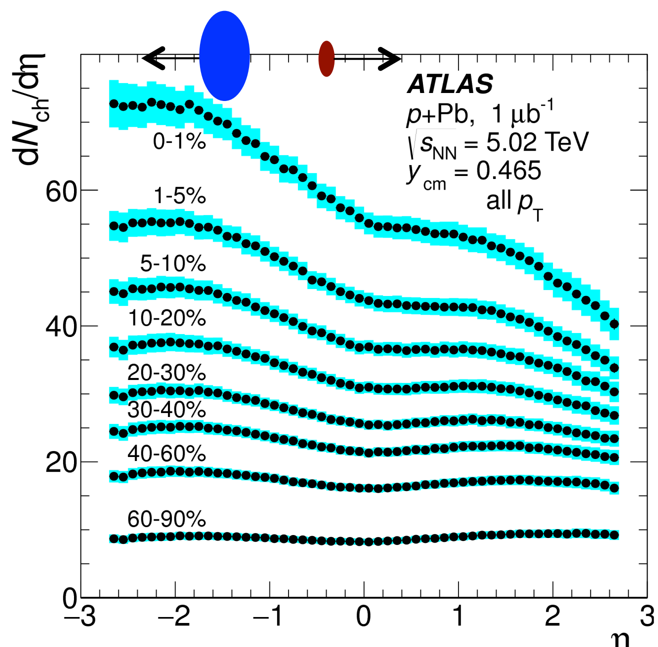
- LRC: num. of sources, n, controlled by N_{ch}, think in terms of partons !
- SRC: pp vs PbPb at same N_{ch} → n is similar but pairs/source is larger?

Features of dN/dη distribution

Double hump→ y to η or FB asymmetry?

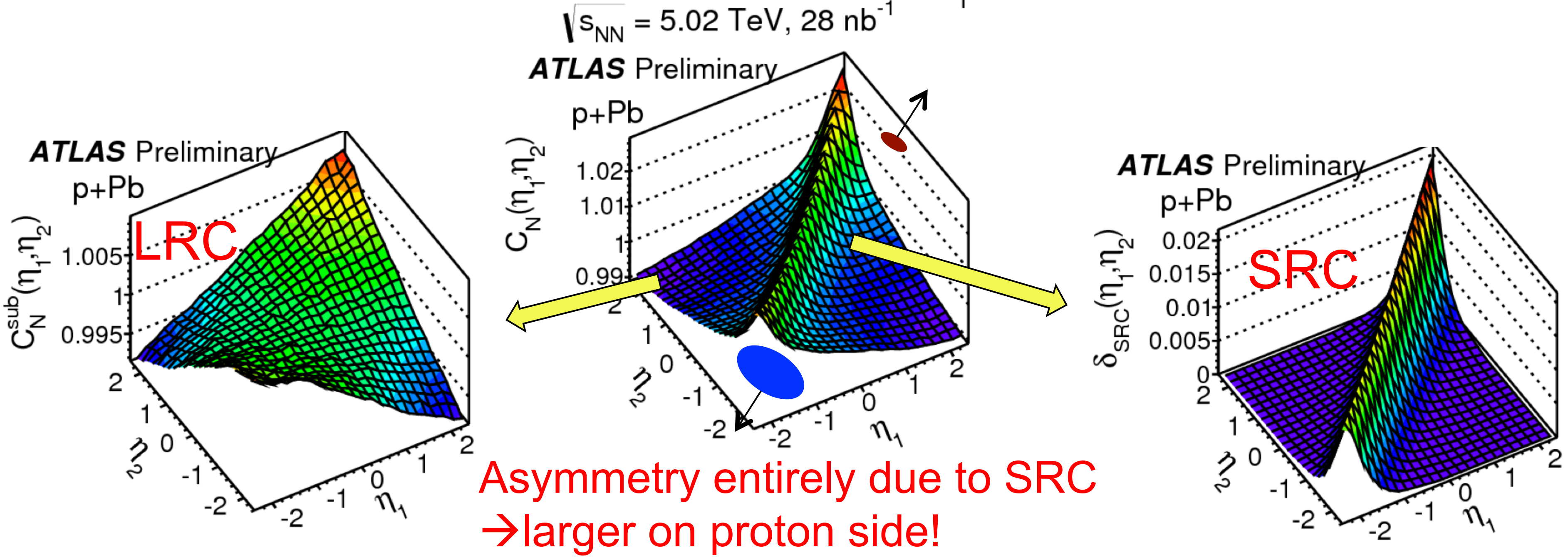




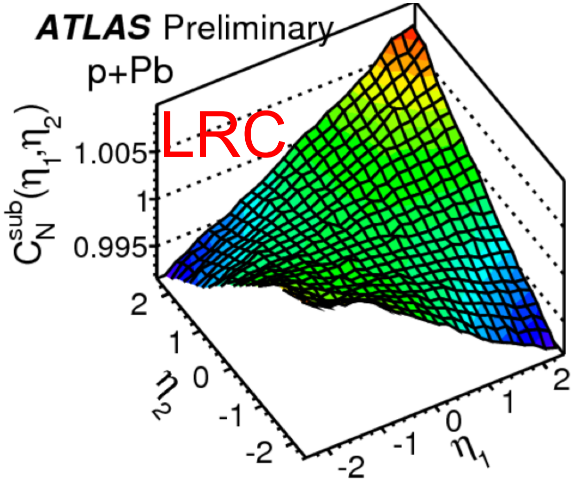


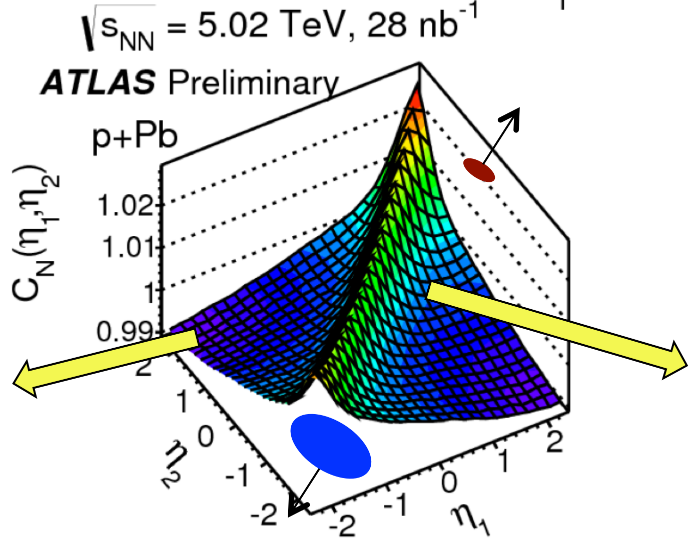
p+A collision suggest it is the latter

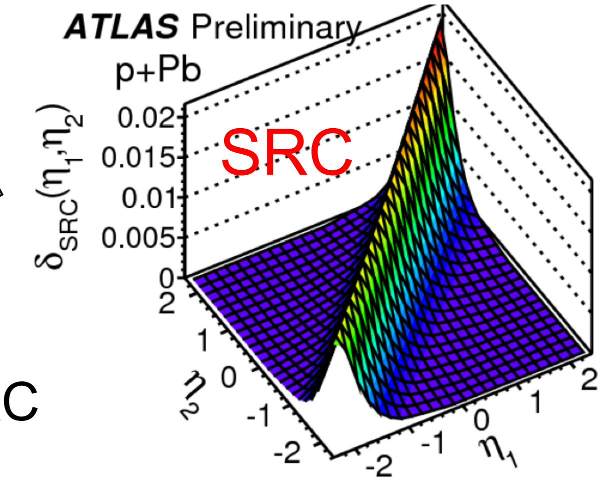
→p+p FB fluctuation is even larger!



$\sqrt{s_{NN}}$ = 5.02 TeV, 28 nb^{-1}
ATLAS Preliminary
p+Pb
LRC
SRC
$C_N^{sub}(\eta_1,\eta_2)$
$C_N(\eta_1,\eta_2)$
$\delta_{SRC}(\eta_1,\eta_2)$
η_1
η_2
Asymmetry entirely due to SRC
→larger on proton side!

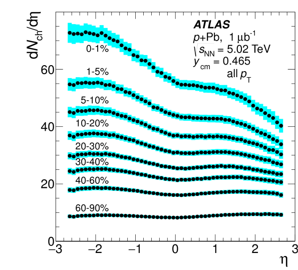






Asymmetry entirely due to SRC
→larger on proton side!

- SRC at given η scale as $\approx \frac{n_{source} m^2}{(n_{source} m)^2} = \frac{1}{n_{source}} \propto 1/dN/d\eta$

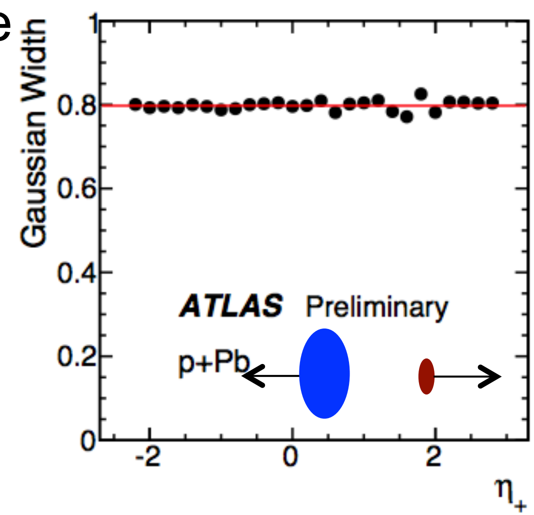


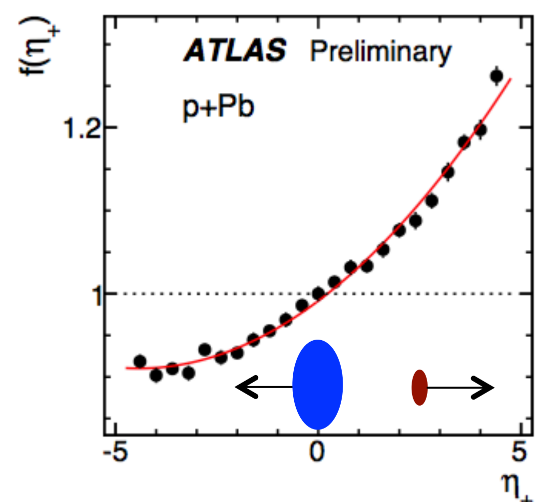
→ Strength of SRC vs η_+ reflects ebye fluctuation of dN/dη shape

→ Amplitude increase on p-side

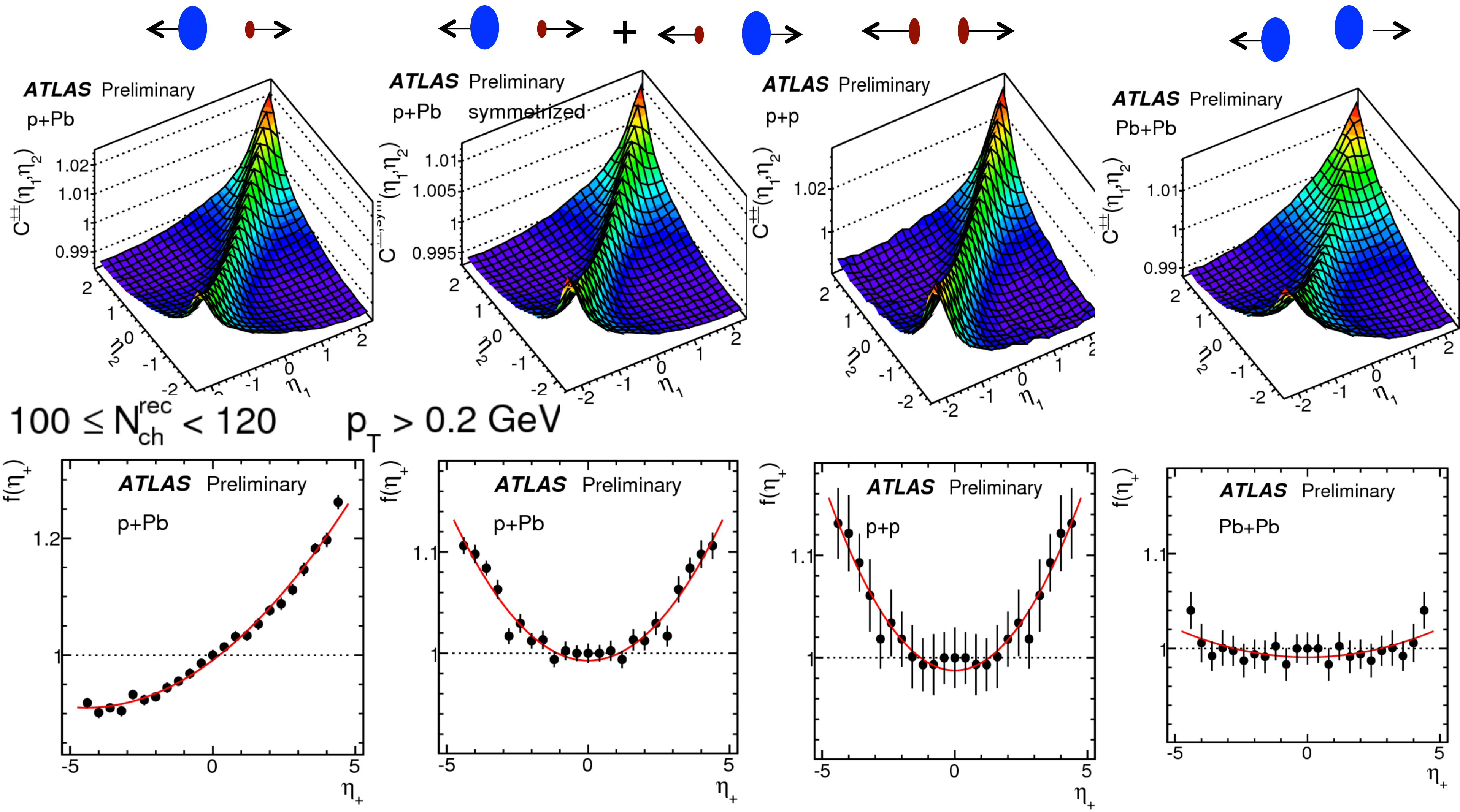
→ Width unchanged

$$\eta_+ = \eta_1 + \eta_2$$
$$\eta_- = \eta_1 - \eta_2$$





Compare pp with p+Pb at same N_{ch}



- High-multi. pp has same η correlation as symmetrized p+Pb given N_{ch}

  → Ebye asym. of dN/dη in high-multi. pp is as large as that in pPb!!

  → Pb+Pb collision more symmetric.

Summary

- Longi. corr. constraint initial conditions for trans. corr.
  - Size, and shape of the initial condition as a function of η

- Longitudinal flow decorrelations
  - Partially consistent with wounded nucleon model

- Longitudinal multiplicity correlations
  - LRC controlled by N_{ch}
  - SRC depends strongly on collision system and charge combination
  - Both follows power-law of N_{ch} with an index close to 0.5 $\rightarrow$ information on the number of sources for particle production?

  - FB asymmetry in pp is as strong as pPb in same multiplicity
    - High multiplicity pp collision is highly asymmetric system
    - Similar longitudinal initial condition in high multiplicity pPb and pp?